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(54) POWER CONVERTER CONTROL AND OPERATION

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(56) References cited:

EP-A2- 2 360 375 EP-A2- 2 706 643
WO-A1-2010/002402 US-A1- 2010 320 762

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Description

[0001] The present invention relates to methods for operating a wind turbine. The present invention also relates to wind turbines including a generator connected to a power converter.

BACKGROUND

[0002] Modern wind turbines are commonly used to supply electricity into the electrical grid. Wind turbines of this kind generally comprise a tower and a rotor arranged on the tower. The rotor, which typically comprises a hub and a plurality of blades, is set into rotation under the influence of the wind on the blades. Said rotation generates a torque that is normally transmitted through a rotor shaft to an electrical generator, either directly ("directly driven") or through the use of a gearbox. This way, the electrical generator produces electricity which can be supplied to the electrical grid.

[0003] The generator may be connected to the electrical grid through a power converter. Such a power converter may include a line-side converter connected to the grid, a machine-side converter connected to a rotor of the generator and a DC-link between the line-side converter and machine-side converter.

[0004] The power converter regulates the power output from the generator to the grid, and can control the torque applied to the generator stator. In normal operation of a wind turbine, the active power produced by the generator will be injected into the grid. The power that can be produced by a generator depends on the prevailing wind speed, but also depends on the torque applied to the generator stator. The control of the wind turbine will generally depend on the prevailing wind speed, and the pitch angle of the blades and torque applied to the stator will generally be chosen such as to maximize electrical power generation and electrical power injection into the grid.

[0005] However, in some circumstances, an abnormality may occur on the grid, e.g. a high frequency. In accordance with some grid codes, the wind turbine should be able to reduce active power output from the generator towards the grid. For example, a grid code may prescribe the ability to reduce active power output at 25% per second. Other grid conditions can also occur in which there is no abnormality (yet), but an active power reduction is requested from a wind turbine, or from a wind park.

[0006] Document WO201002402 discloses a system for connecting a wind turbine generator to a utility power network, with low voltage ride through capability. The system includes a first power converter that converts an AC signal from the wind turbine generator to a DC signal and supplies a controlled amount of reactive current to the wind turbine generator. The system also includes a second power converter, connected in series with the first converter, which converts the DC signal from the first power converter to a line-side AC signal and supplies a

controlled amount of current to the utility power network. A power dissipation element is coupled to the first and second power converters for dissipating power from the first power converter.

[0007] US2010320762 A1 discloses a wind energy installation having a double-energized asynchronous generator and converter control and a method for controlling a converter of a wind energy installation. The converter is connected to the rotor of a doubly-fed asynchronous generator in order to feed electrical power into an electrical grid and comprises a generator-side inverter, a grid-side inverter, and at least one converter regulator for regulating and/or controlling current output from at least one of the inverters to the doubly-fed asynchronous generator and/or to the electrical grid. The method includes detecting a change in output real power, determining whether the detected change satisfies a predefined condition, and changing a nominal value of reactive power to be output in an opposite sense to a change in real power at the grid-side inverter and in a same sense as the generator-side inverter when the predefined condition is satisfied.

[0008] The present invention relates to methods and systems designed to be able to cope with such grid conditions.

SUMMARY

[0009] The present invention is defined by a method of operating a wind turbine having a generator and a power converter with the steps of independent claim 1, and by a wind turbine with the technical features of independent claim 12.

[0010] In accordance with the invention, a different power set-point is provided for the line-side converter than for the machine-side converter. The power set-point for the line-side converter may be chosen such as to comply e.g. with a grid requirement in a given moment. A different power set-point is chosen for the machine-side converter. A divergence between the two set-points is allowed in order to avoid operational problems of the generator or the (wind) turbine connected to it.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Non-limiting examples of the present disclosure will be described in the following, with reference to the appended drawings, in which:

Figure 1 illustrates a perspective view of a wind turbine according to one example of the present disclosure;

Figure 2 illustrates a simplified, internal view of a nacelle of a wind turbine according to one example of the present disclosure;

Figure 3 schematically illustrates a method of operating a wind turbine and a power converter in ac-

cordance with an example of the prior art;

Figure 4 schematically illustrates a method of operating a wind turbine and a power converter in accordance with an example of the present disclosure;

Figure 5 schematically illustrates a method of operating a wind turbine and a power converter in case of a grid disturbance in accordance with an example of the present disclosure; and

Figure 6 schematically illustrates a method of operating a power converter in accordance with a further example.

DETAILED DESCRIPTION OF EXAMPLES

[0012] In these figures the same reference signs have been used to designate matching elements.

[0013] Figure 1 illustrates a perspective view of one example of a wind turbine 1. As shown, the wind turbine 1 includes a tower 2 extending from a support surface 3, a nacelle 4 mounted on the tower 2, and a rotor 5 coupled to the nacelle 4 at a front region. The rotor 5 includes a rotatable hub 6 and at least one rotor blade 7 coupled to and extending outwardly from the hub 6. For example, in the illustrated example, the rotor 5 includes three rotor blades 7. However, in an alternative embodiment, the rotor 5 may include more or less than three rotor blades 7. Each rotor blade 7 may be spaced from the hub 6 to facilitate rotating the rotor 5 to enable kinetic energy to be transferred from the wind into usable mechanical energy, and subsequently, electrical energy. For instance, the hub 6 may be rotatably coupled to an electric generator 10 (Figure 2) positioned within the nacelle 4 or forming part of the nacelle to permit electrical energy to be produced. The rotation of the rotor may be directly transmitted, e.g. in direct drive wind turbines, or through the use of a gearbox to a generator.

[0014] Figure 2 illustrates a simplified, internal view of one example of the nacelle 4 of the wind turbine 1 of the Figure 1. As shown, the generator 10 may be disposed within the nacelle 4. In general, the generator 10 may be coupled to the rotor 5 of the wind turbine 1 for generating electrical power from the rotational energy generated by the rotor 5. For example, the rotor 5 may include a main rotor shaft 8 coupled to the hub 6 for rotation therewith. The generator 10 may then be coupled to the rotor shaft 8 such that rotation of the rotor shaft 8 drives the generator 10. For instance, in the illustrated embodiment, the generator 10 includes a generator shaft 11 rotatably coupled to the rotor shaft 8 through a gearbox 9. In alternative examples, the hub may be directly coupled to a rotor of the generator and the rotation of the hub may thus drive the rotor of the generator.

[0015] The generator 10 may be electrically coupled to the converter. The wind turbine converter may adapt the output electrical power of the generator to the require-

ments of the electrical grid.

[0016] It should be appreciated that the rotor shaft 8, gearbox 9, and generator 10 may generally be supported within the nacelle 4 by a bedplate or a support frame 12 positioned atop the wind turbine tower 2.

[0017] The nacelle 4 is rotatably coupled to the tower 2 through a yaw system 20. The yaw system comprises a yaw bearing (not visible in Figure 2) having two bearing components configured to rotate with respect to the other. The tower 2 is coupled to one of the bearing components and the bedplate or support frame 12 of the nacelle 4 is coupled to the other bearing component. The yaw system 20 comprises an annular gear 21 and a plurality of yaw drives 22 with a motor 23, a gearbox 24 and a pinion 25 for meshing with the annular gear for rotating one of the bearing components with respect to the other.

[0018] The nacelle 4 further comprises a cover structure 50 to house wind turbine components. In this example, wind turbine components housed in the cover structure 50 or enclosed by the cover structure comprise the generator 10, the converter, the gearbox 9 and the shaft 8. In other examples, wind turbine components arranged within the nacelle may refer to the converter and the generator.

[0019] Figure 3 schematically illustrates a method of operating a wind turbine and a power converter in accordance with an example of the prior art. In the example of figure 3, a wind turbine comprises a generator 10, which is connected to an electrical grid 80 through a power converter 60. In this particular example, the generator 10 is a permanent magnet generator, including a generator rotor carrying a plurality of permanent magnets. The permanent magnet generator may be directly driven (i.e. without a gearbox) by the wind turbine rotor 5. The wind turbine in this example may be an offshore wind turbine. In this particular example, the stator of the generator 10 is connected to a machine-side converter 62. The machine side converter is connected to a line-side converter 66 through a DC link 64.

[0020] The generator 10 is configured to convert mechanical energy to electrical energy having AC voltage and current, and provides the generated AC to the machine-side converter 62. The AC from the generator has a variable frequency, due to varying wind conditions. The machine-side converter 62 is configured to convert or rectify the AC to DC voltage and current delivered to the DC-link 64. The line-side converter 66 converts the DC on the DC-link 64 into fixed frequency AC for the grid 80. The line-side converter 66 may be connected to the grid 80 through a main transformer 70.

[0021] In accordance with this example, the power converter 60 receives a single set-point 92 from a controller 90 of the wind turbine. The set-point 92 is based on an optimum operation of the wind turbine in accordance with prevailing meteorological conditions. By controlling the generator torque, a speed of rotation of the generator can be controlled. The speed of rotation of the generator in turn determines the speed of rotation of a wind turbine

rotor 5. The speed of rotation may be chosen in accordance with a predefined operation schedule. In particular, it is known to control the wind turbine differently in different wind speed ranges. In wind speed ranges below a nominal wind speed, the speed of rotation may be chosen such that wind impinges on the blades of the rotor at an optimum angle of attack. This method of operating can be maintained until a maximum speed of rotation is achieved.

[0022] At higher wind speeds, and in particular above the nominal wind speed, the speed of rotation may be controlled to keep it constant. Maximum torque may be applied to the stator and the blades may be pitched to ensure a constant speed of rotation. Variations with respect to such an optimized operation are possible.

[0023] In accordance with the predefined operation, a torque signal 92 may be sent to the machine-side converter by a controller of the wind turbine. The resulting active power output 100 is fed to the grid. The controller 90 of the wind turbine may be a local wind turbine controller, or maybe e.g. a controller for a wind farm.

[0024] Figure 4 schematically illustrates a method of operating a wind turbine and a power converter in accordance with an example of the present disclosure. As in the example of figure 3, the wind turbine may comprise a permanent magnet generator 10 having a rotor carrying a plurality of magnets. As in the example of figure 3, the generator is connected to the electrical grid 80 through a power converter 60.

[0025] The power converter comprises a line-side converter 66, a machine-side converter 62 and a DC-link 64. The wind turbine further includes a controller 90, wherein the controller is configured to determine a first power setpoint 94 in response to e.g. a grid condition and send the first power setpoint 94 to the line-side converter 66 and to determine a second power setpoint 92 in response to the grid condition and send the second power setpoint 92 to the machine-side converter 62. The second power setpoint 92 is higher than the first power setpoint 94.

[0026] In accordance with the second set-point, the generator 10 has a power output 100. However, in accordance with the first set-point, an amount of active power 104 is fed to the grid.

[0027] The wind turbine comprises one or more resistive elements in the DC-link, and the power converter is configured to dissipate a surplus of power from the generator in the resistive elements. The DC-link may include a DC-chopper 68 to dissipate the surplus of power from the generator that cannot be absorbed by the grid. When needed, a switch in the DC-chopper may be closed to divert electrical current through the chopper.

[0028] The power delivered by the machine-side converter on the one hand, and the power supplied to the grid on the other hand by the line-side converter indirectly control the operation of the DC-chopper. The setpoints are power setpoints, unlike in the prior art where it is usual to have a setpoint for the voltage at the DC-link and to operate a chopper as a function of the voltage at

the DC-link.

[0029] The operation based on separate power setpoints allows the converter and the wind turbine to reliably cope with different situations, including different grid abnormalities.

[0030] In accordance with this example, a method of operating a wind turbine is provided. The method comprises determining a reduced first power setpoint 94 in response to an operation condition; reducing active power 104 according to the reduced first power setpoint 94 from a line-side converter 66 to the grid 80; determining a reduced power setpoint for a machine-side converter; and reducing a torque applied to the generator 10 by a machine-side converter 62 such that active power according to the reduced second power setpoint 92 is produced by the generator. The method furthermore comprises dissipating a power surplus (100 - 104) in one or more resistive elements 68 as long as the second power setpoint is superior to the first power setpoint.

[0031] The operational condition may be a grid condition, which may be an abnormal grid condition. The grid condition may be a grid frequency above a predefined threshold. Frequency on the grid may be controlled by the amount of active power supplied to the grid. In response to a high frequency, the wind turbine may be required to reduce the active power output to the grid. Such a response may be defined in a grid code. In accordance with the prior art operation, the generator torque might be reduced. If the generator torque is reduced, the speed of the rotor 5 will tend to increase. This might be counteracted by a brake system and/or by pitching the blades so as to reduce the aerodynamic energy converted. Depending on the wind turbine, such actions may not be sufficient to reduce active power output in accordance with the grid disturbance and grid code.

[0032] In accordance with the example disclosed herein, a first nominal power set-point 94 is sent to the line-side converter 66. The line-side converter 66 receives the first set-point and injects electricity 104 to the grid in accordance with this (reduced) set-point 94. At the same time, a second set-point 92 is sent to the machine-side converter 62. In some examples, the reduced second power setpoint 92 is reduced according to a maximum reduction rate. And in some examples, the maximum reduction rate may be determined so as to avoid an overspeed of a rotor 5 of the wind turbine. In other examples, the maximum reduction rate may be determined so as to avoid loads above an acceptable level.

[0033] The controller 90 may measure electric variables at the grid (e.g. voltage, frequency, phase angle etc.) and determine a grid condition or grid abnormality autonomously. The wind turbine controller may calculate or otherwise determine a suitable set-point reduction signal. In other case, the controller 90 may receive a set-point reduction signal 98 from the grid. The grid condition may be a particularly high frequency of the grid. Another condition may be a voltage abnormality.

[0034] By implementing this control, a wind turbine

may be able to comply with grid code requirements. In other cases, the control may serve to reduce loads on the wind turbine.

[0035] In some examples, the reduced first power set-point may be received by the wind turbine from a grid operator. In other examples, the reduced first power set-point may be determined by the wind turbine, or the controller of the wind turbine. Specifically, the wind turbine may measure a grid frequency and determine an appropriate response. In yet further examples, the wind turbine may receive a measured grid frequency from another entity, e.g. a grid operator or a wind farm controller.

[0036] In another example, the grid condition or grid abnormality may be a voltage sag. A voltage sag or "voltage dip" is a sudden increase of voltage of the electrical grid. The voltage in such a sag may be reduced to e.g. 90% or lower of the nominal voltage. In particular, in a voltage sag, a voltage on the grid may be reduced to 30, 20 or 10 % of the nominal voltage and may even reach 0 V. A duration of a voltage sag may be very short, but may reach a few seconds.

[0037] Grid codes may prescribe that in these conditions, the wind turbine must stay connected to the grid. Similarly as before, first and second power setpoints may be generated for the machine-side and line-side converters. And a surplus of power may be burnt in resistive elements, e.g. a chopper in the DC-link.

[0038] In yet a further example, the operational condition may be required or planned shutdown of the wind turbine. When operation is to be interrupted, in a similar manner as before, first and second power setpoints may be generated. The setpoint for the line-side converter in this case is not necessarily prescribed by a grid code.

[0039] In some examples, while reducing the generator torque, the method may further comprise pitching blades of a wind turbine rotor to reduce rotational speed of the wind turbine rotor. In accordance with the reduction of the rotational speed of the wind turbine rotor, the second reduced power set-point 92 may be further reduced. A surplus of electrical energy might still be dissipated in the resistive elements. The second reduced power set-point 92 may be reduced in accordance with circumstances until the active power produced by the generator 100 can be fed to the grid 80. Until such a situation is reached, the surplus electrical energy may be burnt in resistors.

[0040] In some examples, the method may further comprise monitoring an operation of the resistive elements to avoid the resistive elements reach an operational limit. For example, the method may comprise measuring a temperature of the one or more resistive elements, e.g. in the DC-chopper 68. The temperature in the resistive elements may be measured to make sure they do not reach a critical temperature at which they may fail. Alternatively, the accumulative amount of energy dissipated in the resistive elements may be monitored or calculated. Based on the amount of energy that has been dissipated, it can be calculated or estimated that the resistive elements are close to their operational limits.

[0041] In some examples, the method may further comprise dissipating less energy if one or more of the resistive elements reach one of their operational limits. For example, less energy may be dissipated in the resistive elements if the temperature of the resistive elements surpasses a threshold, if the actuation time of the resistive elements surpasses a time threshold, or if the amount of energy that has been dissipated reaches a predetermined level. In some circumstances this can mean that more active power needs to be delivered to the grid than is desirable or prescribed by a grid code. This may be done to avoid tripping of the converter or the wind turbine.

[0042] In some examples, the method may further comprise increasing the power output once the grid condition has been resolved. Once the grid condition has been resolved, the wind turbine may be operated again to optimize power output. In these conditions, the control of the power converter may switch back to normal operation in which a single set-point is sent to the power converter to determine the generator torque.

[0043] In some examples, method may further comprise ensuring that the rotor speed of the wind turbine does not decrease below a threshold at which the wind turbine becomes hard to control. If necessary, power output may be increased to ensure a minimum rotor speed.

[0044] In this particular example, the generator is a permanent magnet generator, and the power converter is a full power converter. In this particular example, the wind turbine may be an offshore direct drive wind turbine. In another example (figure 6), the generator may be a doubly-fed induction generator (DFIG), and the drive train may include a gearbox.

[0045] Figure 5 schematically illustrates a method of operating a power converter in case of a grid disturbance in accordance with an example of the present disclosure. In particular, the power converter may be connected to a generator driven turbine, specifically a generator driven by a wind turbine.

[0046] A method for operating a power converter connected to an electrical grid is illustrated. The power converter comprises a machine-side converter, a dc-link and a line-side converter. The method comprises determining a grid abnormality; determining a first set-point for active power output of the line-side converter in accordance with the grid abnormality; determining a second set-point for active power output of the rotor-side converter, wherein the second set-point is different from the first set-point.

[0047] During a first part (left hand side of the graph), the converter is operated normally. There is no specific grid abnormality or grid condition that requires an active power reduction. In these circumstances, the only commands received by the power converter is a command relating to the machine-side converter. In this particular example, nominal power may be generated P_{nom} . In the case of an offshore wind turbine, P_{nom} may be e.g. 6 MW, 10 MW or 12 MW.

[0048] When a frequency swell occurs on the grid at t_0 , two set-points instead P_1 , P_2 may be sent. The "fre-

quency control mode" may be activated. In this frequency control mode, a first set-point P_1 for the grid-side converter, and a second set-point P_2 for the machine-side converter are determined (e.g. calculated) separately. It may be seen in the graph, that the set-point P_1 for the grid-side converter may be rapidly reduced to comply with grid conditions. The second set-point P_2 cannot be reduced quickly as it might lead to unsafe condition for the wind turbine, or to high loads due to an overspeed of the wind turbine rotor. The ramp of the second set-point may be as high as possible to avoid such problems. In one example, the ramp may be e.g. 0.4 MW/s. In comparison, the ramp for the reduction of P_1 may be e.g. two - four times higher and the reduced power output may be reached at t_1 .

[0049] It may be seen in the graph, that as long as the second-power setpoint P_2 is higher than the first set-point P_1 (until t_2), energy needs to be dissipated. This may be done by passing electrical current through one or more resistors in the DC-link.

[0050] At t_2 , the second set-point is equal to the first set-point. This means that the power output from the generator is injected into the grid and no further electrical energy needs to be dissipated. The power produced by the generator P_{red} may be smaller than in normal operation before the grid abnormality.

[0051] At $t = t_3$, there is still a grid condition but the frequency swell is lower than it was in the beginning of the grid condition. The first set-point of the machine side converter P_1 may thus be increased, and at the same time, the second set-point P_2 may also be increased. Power output may thus be increased without the need for dissipating energy in the resistors.

[0052] At $t = t_4$, the grid returns to normal conditions. The frequency control mode may be deactivated and normal operation may be resumed. The first set-point for the grid side converter is no longer sent to the converter. The machine-side converter is controlled to gradually increase the power output to return to normal conditions at t_5 .

[0053] Figure 6 schematically illustrates a method of operating a power converter 60 in accordance with a further example.

[0054] In this particular example (similarly to the arrangement of figure 4), the wind turbine comprises a wind turbine rotor 5 with a plurality of blades, and a generator 10 operatively connected with the wind turbine rotor 5, and a power converter 60 electrically connecting the generator 10 to an electrical grid 80, wherein the power converter 60 includes a line-side converter 66, a machine-side converter 62 and a DC-link 64. The wind turbine in this example further comprises a controller 90. The controller may be configured to determine a first power setpoint 94 in response to a grid condition and send the first power setpoint 94 to the line-side converter 66 and to determine a second power setpoint 92 in response to the grid condition and send the second power setpoint 92 to the machine-side converter 62, wherein the second power

setpoint 92 is higher than the first power setpoint 94.

[0055] In this particular example of figure 6, the generator 10 may be a doubly fed induction generator (DFIG). The generator 10 may be driven by a gearbox 9. With this specific topology of the generator, the machine-side converter 62 is electrically connected with the generator rotor. The stator of the generator is directly coupled with the electrical grid. "Directly" as used herein means that there is no converter in between the stator and the grid. Depending on the circumstances, a transformer may be arranged between the grid 80 and the stator.

[0056] The operation of the wind turbine and converter may generally be the same as was described before with reference to figures 4 and 5. The methods of operating may be more effective in the configuration with a permanent magnet generator and a full power converter because all electrical power passes through the converter, as opposed to the DFIG configuration of figure 6.

[0057] This written description uses examples to disclose the invention, including the preferred embodiments, and also to enable any person skilled in the art to practice the invention. The scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims.

Claims

1. A method of operating a wind turbine (1) having a generator (10) and a power converter (60) electrically coupled to the generator (10), wherein the power converter (60) comprises a machine-side converter (62) connected to the generator (10), a line-side converter (66) connected to an electrical grid (80), and a DC-link (64) through which the machine-side converter (62) is connected to the line-side converter (66), the method comprising:

determining a reduced first active power setpoint (94) in response to an operational condition;

reducing active power from the line-side converter (66) to the electrical grid (80) according to the reduced first active power setpoint (94);

determining a reduced second active power setpoint (92) for the machine-side converter (62), the reduced second power setpoint (92) being higher than the reduced first active power setpoint (94);

reducing a torque applied to the generator (10) by the machine-side converter (62) such that active power according to the reduced second active power setpoint (92) is produced by the generator (10); and

- dissipating an active power surplus from the generator (10) in one or more resistive elements (68) in the DC-link (64) as long as the reduced second active power setpoint is superior to the reduced first active power setpoint. 5
2. The method according to claim 1, wherein the operational condition is a condition of the electrical grid.
 3. The method according to claim 2, wherein the operational condition of the electrical grid is an increase in frequency of the grid. 10
 4. The method according to claim 2, wherein the operational condition of the electrical grid is a voltage sag. 15
 5. The method according to any of claims 1 - 4, wherein the reduced second active power setpoint (92) is reduced according to a maximum reduction rate. 20
 6. The method according to claim 5, wherein the maximum reduction rate is determined to avoid an over-speed of a rotor (5) of the wind turbine (1).
 7. The method according to any of claims 1 - 6, wherein the reduced first active power setpoint (92) is received by the wind turbine (1) from a grid operator. 25
 8. The method according to any of claims 1 - 6, wherein the reduced first active power setpoint (92) is determined by the wind turbine (1) in response to a measured electrical grid variable. 30
 9. The method according to any of claims 1 - 8, further comprising pitching blades (7) of a wind turbine rotor (5) to reduce rotational speed of the wind turbine rotor (5). 35
 10. The method according to any of claims 1 - 9, further comprising monitoring an operation of the resistive elements (68) to avoid the resistive elements (68) reaching an operational limit, and dissipating less energy in the resistive elements (68) if one or more of the resistive elements (68) reach an operational limit. 40 45
 11. The method according to any of claims 2 - 10, further comprising increasing the power output of the generator (10) once the condition of the electrical grid (80) has been resolved. 50
 12. A wind turbine (1) comprising:
 - a wind turbine rotor (5) with a plurality of blades (7), 55
 - a generator (10) operatively connected with the wind turbine rotor (5),
 - a power converter (60) electrically connecting

the generator (10) to an electrical grid (80), wherein the power converter (60) includes a line-side converter (66) connected to the electrical grid (80), a machine-side converter (62) connected to the generator (10) and a DC-link (64) through which the machine-side converter (62) is connected to the line-side converter (66), and a controller (90), wherein the controller (90) is configured to determine a reduced first active power setpoint (94) in response to a grid condition and send the reduced first active power setpoint (94) to the line-side converter (66) and to determine a reduced second active power setpoint (92) in response to the grid condition and send the reduced second active power setpoint (92) to the machine-side converter (62), wherein the reduced second power setpoint (92) is higher than the reduced first active power setpoint (94), and wherein, the DC-link comprises one or more resistive elements (68), and the power converter (60) is configured to dissipate a surplus of power from the generator (10) in the resistive elements (68) as long as the reduced second active power setpoint is superior to the reduced first active power setpoint.

13. The wind turbine according to claim 12, wherein the controller is configured to lower the second active power setpoint (92) at 0.4 MW/s.
14. The wind turbine according to any of claims 12 - 13, wherein the generator (10) is a permanent magnet generator, and the power converter is a full power converter.

Patentansprüche

1. Verfahren zum Betreiben einer Windturbine (1) mit einem Generator (10) und einem mit dem Generator (10) elektrisch gekoppelten Leistungsumrichter (60), wobei der Leistungsumrichter (60) einen mit dem Generator (10) verbundenen maschinenseitigen Umrichter (62), einen mit einem elektrischen Netz (80) verbundenen netzseitigen Umrichter (66) und einen Gleichstromzwischenkreis (64) umfasst, über den der maschinenseitige Umrichter (62) mit dem netzseitigen Umrichter (66) verbunden ist, wobei das Verfahren umfasst:

Bestimmung eines reduzierten ersten Wirkleistungssollwerts (94) als Reaktion auf eine Betriebsbedingung;
 Reduzierung der Wirkleistung vom netzseitigen Umrichter (66) zum elektrischen Netz (80) entsprechend dem reduzierten ersten Wirkleis-

- tungssollwert (94);
Bestimmung eines reduzierten zweiten Wirkleistungssollwerts (92) für den maschinenseitigen Umrichter (62), wobei der reduzierte zweite Leistungssollwert (92) höher ist als der reduzierte erste Wirkleistungssollwert (94),
5 Reduzieren eines durch den maschinenseitigen Umrichter (62) auf den Generator (10) eingebrachten Drehmoments, so dass Wirkleistung entsprechend dem reduzierten zweiten Wirkleistungssollwert (92) durch den Generator (10) erzeugt wird; und
10 Ableiten eines Wirkleistungsüberschusses des Generators (10) in einem oder mehreren Widerstandselementen (68) im Zwischenkreis (64), solange der reduzierte zweite Wirkleistungssollwert höher ist als der reduzierte erste Wirkleistungssollwert.
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2. Verfahren nach Anspruch 1, wobei der Betriebszustand ein Zustand des elektrischen Netzes ist. 20
3. Verfahren nach Anspruch 2, wobei der Betriebszustand des elektrischen Netzes eine Erhöhung der Netzfrequenz ist. 25
4. Verfahren nach Anspruch 2, wobei der Betriebszustand des elektrischen Netzes ein Spannungsabfall ist. 30
5. Verfahren nach einem der Ansprüche 1 bis 4, wobei der reduzierte zweite Wirkleistungssollwert (92) gemäß einer maximalen Reduktionsrate reduziert wird. 35
6. Verfahren nach Anspruch 5, wobei die maximale Reduktionsrate bestimmt wird, um eine Überdrehzahl eines Rotors (5) der Windkraftanlage (1) zu vermeiden. 40
7. Verfahren nach einem der Ansprüche 1 bis 6, wobei der reduzierte erste Wirkleistungssollwert (92) von der Windkraftanlage (1) von einem Netzbetreiber empfangen wird. 45
8. Verfahren nach einem der Ansprüche 1 bis 6, wobei der reduzierte erste Wirkleistungssollwert (92) von der Windkraftanlage (1) in Abhängigkeit von einer gemessenen elektrischen Netzvariablen bestimmt wird. 50
9. Verfahren nach einem der Ansprüche 1 bis 8, wobei ferner die Blätter (7) eines Windturbinenrotors (5) geneigt werden, um die Drehgeschwindigkeit des Windturbinenrotors (5) zu verringern.
10. Verfahren nach einem der Ansprüche 1 bis 9, ferner umfassend die Überwachung des Betriebs der Widerstandselemente (68), um zu vermeiden, dass die
- Widerstandselemente (68) eine Betriebsgrenze erreichen, und
weniger Energie in den Widerstandselementen (68) zu dissipieren, wenn eines oder mehrere der Widerstandselemente (68) eine Betriebsgrenze erreichen.
11. Verfahren nach einem der Ansprüche 2 bis 10, wobei ferner die Ausgangsleistung des Generators (10) erhöht wird, sobald der Zustand des elektrischen Netzes (80) behoben ist.
12. Eine Windkraftanlage (1), bestehend aus:
- einen Windturbinenrotor (5) mit einer Vielzahl von Blättern (7),
einen Generator (10), der mit dem Rotor (5) der Windkraftanlage verbunden ist,
einen Umrichter (60), der den Generator (10) mit einem elektrischen Netz (80) elektrisch verbindet, wobei der Stromrichter (60) einen mit dem elektrischen Netz (80) verbundenen netzseitigen Stromrichter (66), einen mit dem Generator (10) verbundenen maschinenseitigen Stromrichter (62) und einen Gleichspannungszwischenkreis (64), über den der maschinenseitige Stromrichter (62) mit dem netzseitigen Stromrichter (66) verbunden ist, umfasst, und
eine Steuerung (90), wobei
die Steuerung (90) so konfiguriert ist, dass sie einen reduzierten ersten Wirkleistungssollwert (94) in Reaktion auf eine Netzbedingung bestimmt und den reduzierten ersten Wirkleistungssollwert (94) an den netzseitigen Umrichter (66) sendet und einen reduzierten zweiten Wirkleistungssollwert (92) in Reaktion auf die Netzbedingung bestimmt und den zweiten Wirkleistungssollwert (92) an den maschinenseitigen Umrichter (62) sendet, wobei
der reduzierte zweite Leistungssollwert (92) höher ist als der reduzierte erste Wirkleistungssollwert (94), und wobei,
der DC-Zwischenkreis ein oder mehrere Widerstandselemente (68) umfasst, und der Leistungsumrichter (60) so konfiguriert ist, dass er einen Leistungsüberschuss vom Generator (10) in den Widerstandselementen ableitet, solange der reduzierte zweite Wirkleistungssollwert höher ist als der reduzierte erste Wirkleistungssollwert
13. Windkraftanlage nach Anspruch 12, wobei die Steuerung so konfiguriert ist, dass er den zweiten Wirkleistungssollwert (92) auf um 0,4 MW/s absenkt.
14. Windkraftanlage nach einem der Ansprüche 12 bis 13, wobei der Generator (10) ein Permanentmagnetgenerator ist und der Stromrichter ein Vollstromrichter ist.

Revendications

1. Méthode d'exploitation d'une éolienne (1) comportant un générateur (10) et un convertisseur de puissance (60) couplé électriquement au générateur (10), dans laquelle le convertisseur de puissance (60) comprend un convertisseur côté machine (62) connecté au générateur (10), un convertisseur côté ligne (66) connecté à un réseau électrique (80), et une liaison CC (64) par laquelle le convertisseur côté machine (62) est connecté au convertisseur côté ligne (66), la méthode comprenant :
 - déterminer une première consigne de puissance active réduite (94) en réponse à une condition opérationnelle ;
 - réduire la puissance active du convertisseur côté ligne (66) vers le réseau électrique (80) en fonction de la première valeur de consigne de puissance active réduite (94) ;
 - déterminer une seconde consigne de puissance active réduite (92) pour le convertisseur côté machine (62), la seconde consigne de puissance active réduite (92) étant supérieure à la première consigne de puissance active réduite (94)
 - réduire un couple appliqué au générateur (10) par le convertisseur côté machine (62) de manière à ce que la puissance active selon la seconde consigne de puissance active réduite (92) soit produite par le générateur (10) ; et
 - dissiper un surplus de puissance active du générateur (10) dans un ou plusieurs éléments résistifs (68) de la liaison CC (64) tant que la seconde consigne de puissance active réduite est supérieure à la première consigne de puissance active réduite.
2. Méthode selon la revendication 1, dans laquelle l'état de fonctionnement est une condition du réseau électrique.
3. Méthode selon la revendication 2, dans laquelle la condition opérationnelle du réseau électrique est une augmentation de la fréquence du réseau.
4. Méthode selon la revendication 2, dans laquelle la condition opérationnelle du réseau électrique est une chute de tension.
5. Procédé selon l'une des revendications 1 à 4, dans lequel la seconde consigne de puissance active réduite (92) est réduite en fonction d'un taux de réduction maximal.
6. Méthode selon la revendication 5, dans laquelle le taux de réduction maximal est déterminé pour éviter une survitesse d'un rotor (5) de l'éolienne (1).
7. Procédé selon l'une des revendications 1 à 6, dans lequel la première consigne de puissance active réduite (92) est reçue par l'éolienne (1) de la part d'un opérateur de réseau.
8. Méthode selon l'une des revendications 1 à 6, dans laquelle la première consigne de puissance active réduite (92) est déterminée par l'éolienne (1) en réponse à une variable mesurée du réseau électrique.
9. La méthode selon l'une des revendications 1 à 8, comprenant en outre le tangage des pales (7) d'un rotor d'éolienne (5) pour réduire la vitesse de rotation du rotor d'éolienne (5).
10. La méthode selon l'une des revendications 1 à 9, comprenant en outre la surveillance du fonctionnement des éléments résistifs (68) afin d'éviter que les éléments résistifs (68) n'atteignent une limite opérationnelle, et dissiper moins d'énergie dans les éléments résistifs (68) si un ou plusieurs des éléments résistifs (68) atteignent une limite opérationnelle.
11. La méthode selon l'une des revendications 2 à 10, comprenant en outre l'augmentation de la puissance de sortie du générateur (10) une fois que la condition du réseau électrique (80) a été résolue.
12. Une éolienne (1) comprenant :
 - un rotor d'éolienne (5) avec plusieurs pales (7),
 - un générateur (10) relié de manière opérationnelle au rotor de l'éolienne (5),
 - un convertisseur de puissance (60) connectant électriquement le générateur (10) à un réseau électrique (80), dans lequel le convertisseur de puissance (60) comprend un convertisseur côté ligne (66) connecté au réseau électrique (80), un convertisseur côté machine (62) connecté au générateur (10) et une liaison CC (64) par laquelle le convertisseur côté machine (62) est connecté au convertisseur côté ligne (66), et
 - un contrôleur (90), dans lequel le contrôleur (90) est configuré pour déterminer une première consigne de puissance active réduite (94) en réponse à une condition de réseau et pour envoyer la première consigne de puissance active réduite (94) au convertisseur côté ligne (66) et pour déterminer une deuxième consigne de puissance active réduite (92) en réponse à la condition de réseau et pour envoyer la deuxième consigne de puissance active (92) au convertisseur côté machine (62), dans lequel la seconde consigne de puissance réduite (92) est supérieure à la première consigne de puissance active réduite (94), et dans lequel, la liaison CC comprend un ou plusieurs éléments

ments résistifs (68), et le convertisseur de puissance (60) est configuré pour dissiper un surplus de puissance du générateur (10) dans les éléments résistifs tant que la seconde consigne de puissance active réduite est supérieure à la première consigne de puissance active réduite 5

13. L'éolienne selon la revendication 12, dans laquelle le contrôleur est configuré pour abaisser le second point de consigne de puissance active (92) à 0,4 MW/s. 10

14. L'éolienne selon l'une des revendications 12 à 13, dans laquelle le générateur (10) est un générateur à aimant permanent, et le convertisseur de puissance est un convertisseur pleine puissance. 15

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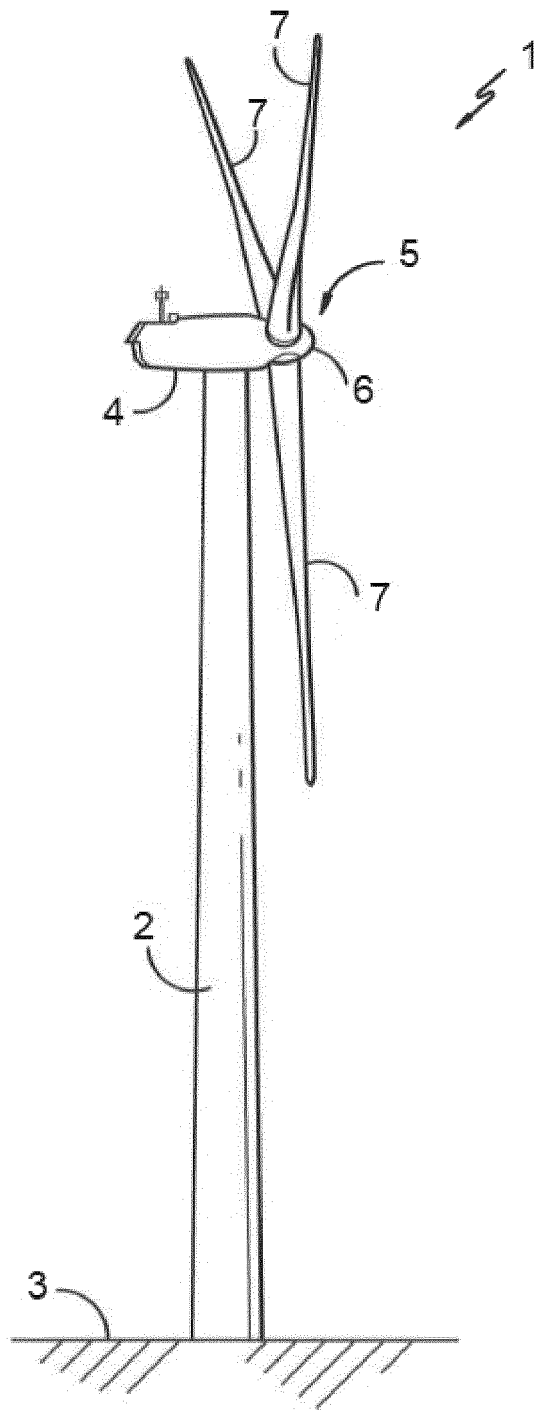


Figure 1

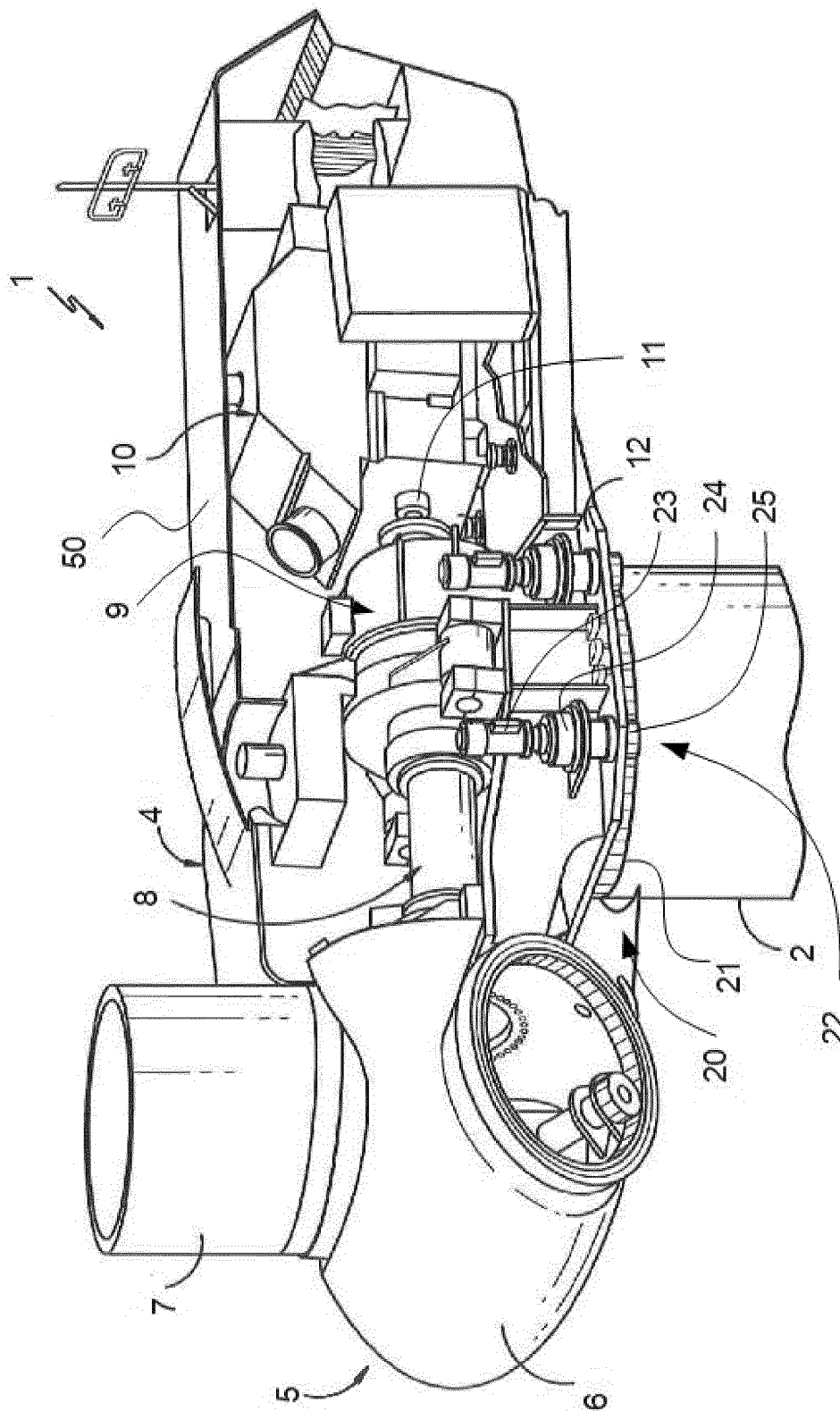


Figure 2

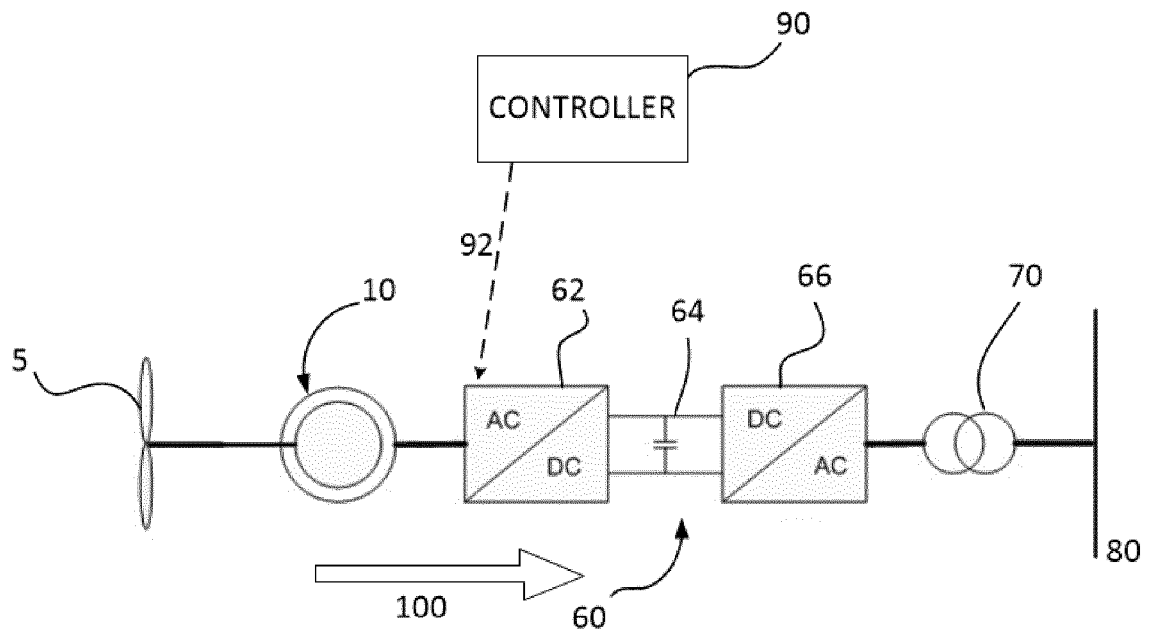


Figure 3

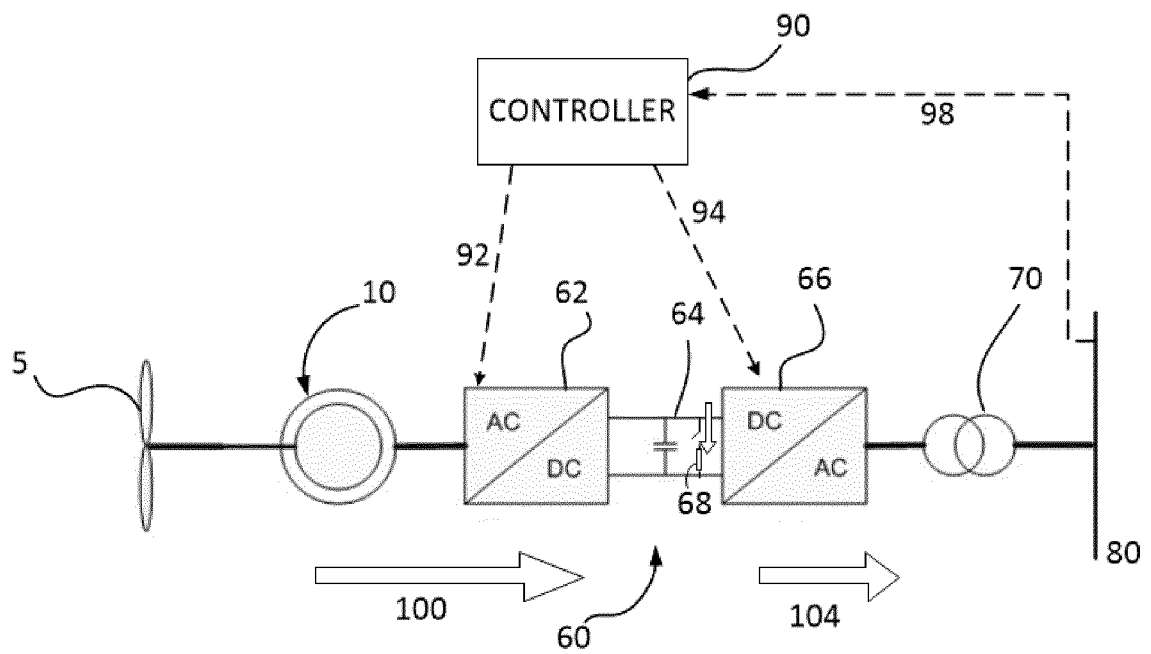


Figure 4

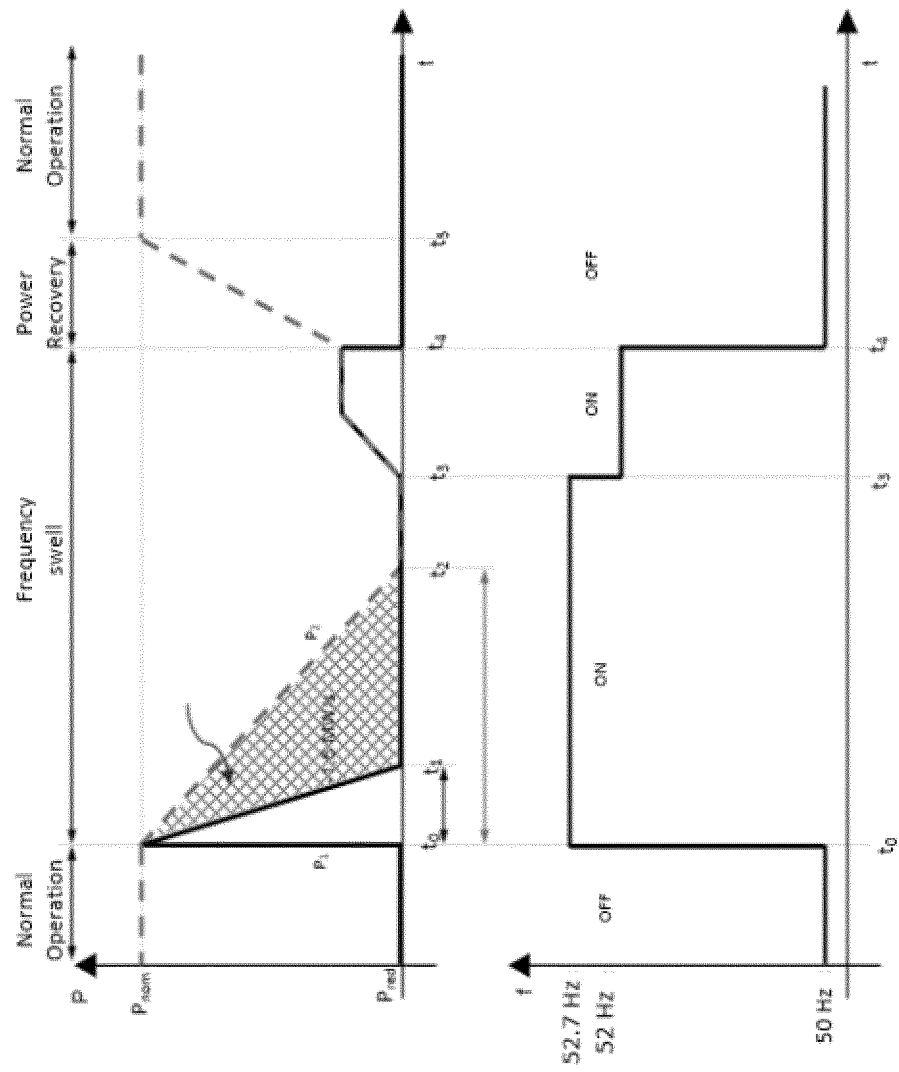


Figure 5

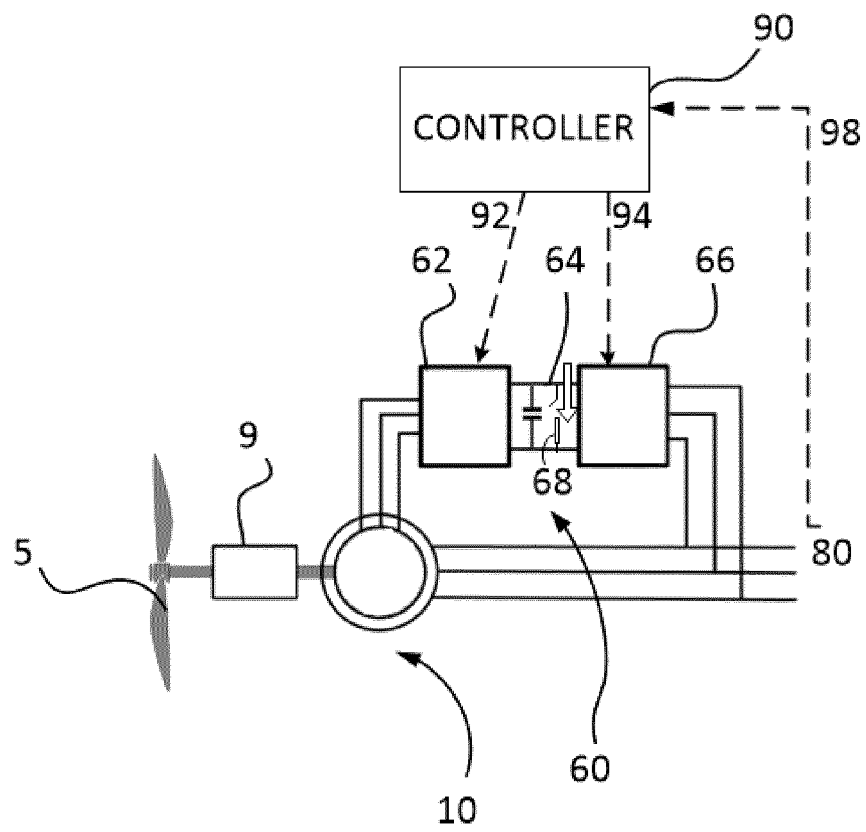


Figure 6

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2010002402 A [0006]
- US 2010320762 A1 [0007]